An Introduction to Warmwater Fish Culture in Utah

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Introduction

In Utah, the demand for warmwater fisheries is increasing. At this time, however, in comparison to coldwater fisheries, the State provides anglers with relatively few warmwater angling opportunities. It is likely that with increased investment in community fisheries and climate change, that the need for warmwater fisheries will increase in the future. The development of a new hatchery could help the State meet this increased warmwater fish demand.

The purpose of this review is to provide a synopsis of the techniques that have been used for the culture of several popular warmwater fish. This review is not intended to provide detailed instructions for the culture of each species. Rather, this manual is intended to provide a brief introduction to the techniques that other agencies use when producing various warmwater fishes. A list of references is provided for each species. These references can be used in the future for the development of detailed culture protocols for each species. This review provides basic information about the culture requirements for each species and can be used as a guide in the design of a warmwater hatchery.

In this review, we provide basic life-history information for each discussed species. This information is provided because an understanding of life-history can aid culturists and improve the success of a hatchery program. We also provide a synopsis of the culture techniques that have been used successfully for each species. Finally, we describe the resources (i.e., culture equipment and numbers of brood) required to produce 100,000 individuals of a size that are typically stocked for each species. Ultimately, Utah may decide to produce more or less than 100,000 individuals of each species. We selected 100,000 as a nominal value and the required materials can be scaled to meet the actual demand for a species.

Our goal is to provide the senior staff and hatchery managers a guide to warmwater fish culture in Utah. This review should aid in the design of a warmwater hatchery. It also provides a list of sources that can be referred to in the future for detailed information on the culture of each species.

Bluegill

Introduction

Bluegill *Lepomis macrochirus* are one of the most popular sport fish in North America. When they are present in a system, their harvest in terms of both numbers and biomass can exceed that of all other species combined (Drake et al. 1997). Bluegill can easily hybridize with other species from the same genus. Bluegill hybrids are not completely sterile (Wills et al. 2000). Green sunfish *Lepomis cyanellus* male x bluegill female hybrids are frequently produced by aquaculturists. These hybrids often grow faster than pure bluegill (Wills et al. 2000). Redear sunfish *L. microphus*, longear sunfish *L. megalotis*, and pumpkinseed *L. gibbosus* have also been cultured. This review will focus on the production of pure bluegill. The methods for culturing hybrid bluegill are similar.

Bluegill have a unique reproductive life history that influences the aquacultural techniques used to produce the species. In the spring, male bluegill construct nests in shallow water (< 3 m). The nests

are typically constructed near the shore. These nests are shallow depressions that are dug into gravel (pea size or less). The nests are typically ~0.3 m in diameter. Bluegill are colonial nesters and typically nest in colonies of 40-50 males (Mischke and Morris 1998). Male bluegill court females to deposit eggs into their nests. After fertilization, the male fans the eggs, picks off fungesed eggs, and defends his nest until his fry swim-up. During this time, males do not leave their nests and they eat little. After the fry leave the nest, the male leaves the nest and resumes feeding. The bluegill spawning season typically lasts from late May-early September. During this time, 10-15 distinct spawning bouts occur (Cargnelli and Neff 2006). Individual fish do not necessarily spawn during every bout (Cargnelli andNeff 2006). The typical fish spawns 3-5 times a year and females only release a portion of their eggs during each bout (Cargnelli and Neff 2006). The unique reproductive life history of bluegill influences the culture techniques utilized for the species. Since bluegill are fractional spawners, hand stripping of eggs typically yields few ripe eggs. As a result, bluegill are typically cultured in ponds. Tank culture of bluegill is feasible, albeit with reduced success. Both methods of bluegill culture are described below. Hand-stripping of bluegill gametes has only been performed as part of research projects requiring small numbers of eggs. The methods for culturing bluegill from hand-stripped gametes at a production scale has not been described in the literature. The hand-stripping of gametes, however, can facilitate in the production of hybrid sunfish. The successful production of triploid green sunfish x bluegill hybrids has been documented in the literature. Wills et al. (1994) found that a pressure shock of 48,264 kPa beginning either 2 or 4 min after fertilization, with an exposure duration of 3-4 min, successfully induced triploidy in 100% of such hybrids.

Eggs hatch 2-3 d after deposition. Fish swim-up and leave their nests 3-7 d after hatch. Immediately after swim-up, bluegill primarily feed on rotifers. As they grow, fish begin to consume larger zooplankton species and insects. At the onset of swim-up, the mouth gape of larval bluegill is 230-270 µm (Mischke and Morris 1998).

During the spawning season, fish can be easily sexed using visual cues. Males are darker in color than females and have a distinct black spot on their dorsal fins. Males also have an orange belly and a slight protrusion on their head whereas females are more uniform in coloration and lack this protrusion. The urogenital pore of a male usually terminates in a funnel shaped pore whereas the urogenital pore of females are swollen and have a "doughnut-like" ring (Mischke and Morris 1998).

There is a large body of literature on the culture of bluegill. Throughout this section, I have added information about my personal experiences with the culture of bluegill in Illinois. While there, I cultured bluegill in both experimental ponds and in tanks. This research was performed in an attempt to identify methods for improving the size of bluegill harvested by anglers. As a result, I did not necessarily use "proper aquaculture techniques" since those techniques were not necessarily compatible with the goals of my research. Still, I think that the research provides useful insight on bluegill culture methods.

Pond Culture

Most agencies culture bluegill in earthen ponds. When cultured in ponds, the size of the pond seems to matter little. Ponds as small as 0.04 h are sufficient for production (Oplinger, personal observation). It is important that any ponds that are used are shallow enough (< 3 m) to provide

opportunity for nest construction (Mischke and Morris 1998). Since bluegill readily hybridize with other species in the genus, it is important that ponds are completely fish-free prior to filling and that the water used for filling the ponds is filtered.

Bluegill have been documented to spawn at temperatures ranging between 20 and 30°C (Dupree and Huner 1984). The optimal spawning temperature appears to be 21°C. The rate of spawning appears to taper off greatly at temperatures in excess of 26°C (Oplinger, personal observation). As long as temperatures are appropriate, bluegill will spawn in ponds throughout the summer. Personal experience has shown, however, that at latitudes similar to Utah (in Illinois) that summer temperatures in ponds ranging in size from 0.04-0.40 ha (1-2.5 m deep) often warm too much in the summer to support reproduction and that most spawning occurs in these ponds early in the summer (Oplinger, personal observation).

Brood fish are typically collected from the wild and are stocked into ponds prior to temperatures reaching 21°C (Mischke and Morris 1998). Bluegill are typically stocked at a 1:1 sex ratio at a density of 250 fish/ha (Mischke and Morris 1998). In the wild, sex ratios are often skewed towards females (Oplinger, personal observation) and males typically mate with multiple females during a spawning bout. Personal experience has shown that fry production is improved if a sex ratio of 1.5-2.0 females:1 male is used (Oplinger, personal observation). Even at low broodstock densities, large numbers of fry can be produced. For example, twelve male and twenty five female bluegill were added to each of eight 0.4 ha ponds in Illinois (92.5 fish/ha)and the number of fingerling recovered three months later ranged between 8,000 and 52,000 (Oplinger, personal observation). Others have stocked brood at densities of 74-600 individuals/ha and have observed production of 100,000-600,000 25 mm TL fingerling (Williamson et al. 1993). Fingerling production is increased with pond fertilization and/or supplemental feeding with artificial feed (Williamson et al. 1993). Cannibalism is low among bluegill. As a result, brood are typically left in the production ponds.

Bluegill often forage on natural prey while in ponds. It has been suggested, however, that there is benefit to adding supplemental floating feed when brood densities exceed 225 kg/ha (Dupree and Huner 1984). It is recommended that at temperatures ≥ 21° C that fish are fed 5-7 times/day at a rate of 3% of total fish biomass/day (Dupree and Huner 1984). At temperatures of 13-21° C, fish should be fed on alternating days at 1-2% of total fish biomass/day. Bluegill are not typically fed at temperatures < 13°C. Bluegill that are provided artificial feed are about 60% heavier at the end of the first growing season than those that are not provided artificial feed (Lovshin and Matthews 2003). Little research on the optimization of an artificial bluegill diet has been performed. Most studies appear to provide bluegill a diet consisting of 36% protein. Webster et al. (1997) attempted to optimize the diet of hybrid bluegill (green sunfish x bluegill). Through a variety of experiments that tested growth, body composition, and feed conversion rates, the authors concluded that these hybrids are best fed a diet containing 35-36% protein with 32% of the protein coming from fish meal (Webster et al. 1997). If provided, artificial feed for swim-up fry should be <250 µm (Mischke and Morris 1998). Most of the data on the growth of bluegill in experimental ponds is based in southern latitudes where growing seasons are extended. Lovshin and Matthews (2003) reared bluegill in Alabama and reported that the fish were approximately 120 mm at 4-5 mo. of age. The fish cited in this study were provided artificial

feed. Personal experience in Illinois suggests that the growth observed by Lovshin and Matthews (2003) is likely not attainable in northern latitudes. Typically bluegill reared in experimental ponds in Illinois were 40-60 mm at 4-5 mo. of age (Oplinger, personal observation). The diets of the bluegill reared in Illinois, however, were not supplemented with artificial feed.

There appears to be little consensus on the average stocking size for bluegill. It appears that agencies stock bluegill at sizes ranging between 25 and 120 mm TL (Williamson et al. 1993). Depending on latitude, these sizes will be obtained in mid-summer or early fall. Bluegill are typically recovered from ponds by either seining or pond draining.

Tank Culture

Bryan et al. (1994) describe methods used for culturing bluegill in tanks. To do this, sexually mature bluegill were collected from the wild at the beginning of the spawning season (late May-early June). The fish were placed into 600 L, circular tanks. The tanks received fresh well water at a rate of 1.0 L/min. Two males and three females were added to each tank. The fish were fed to satiation once daily using Nelson's Sterling Silver Cup salmon diet. The temperature and photoperiod in the tanks were adjusted once a week to match the conditions at the pond that that fish were collected from. When the temperature reached 22°C, two artificial nests were added to each tank. The nests were constructed by cutting off the bottom 3 cm of 10.5 L, Rubbermaid buckets. The insides of the nest were then covered with silicone caulking and pea gravel was pressed into the calking. Spawning occurred 2 d after the addition of the nests. The nests remained in the tanks for 12 h after spawning and then they were removed and placed into a 38 L aquarium that received 250 mL of water/min in a flow-through system. The temperature was adjusted over the next 12 h to 26°C. At this temperature, it took the eggs roughly 36 h to hatch. Three days after hatch, the fry were siphoned off the bottom of the aquarium and were transferred to specially designed 7.7 L volume larval rearing chambers (see Figure 1 of Bryan et al. 1994 for specifications). The fry were fed Artificial Plankton Microcapsules (Argent Chemical Laboratories, Redmond, Washington) every 30 min. During each feeding, 500 mg of feed was added. Starting 9 d post-hatch, brine shrimp nauplii were added in conjunction with the artificial diet (ration of artificial diet not changed). Fourteen days after hatch, the fry were transferred to a 38 L aquarium with a flow-through system. They were fed a mixture of brine shrimp nauplii and *Daphnia* sp. until they reached 30 mm TL. Once they reached 30 mm TL, they were fed an artificial pelleted diet (specific details of diet not provided). The details of the success (hatch rates, numbers of fry produced, etc.) were not reported. Bryan et al. (1994) also provides advice regarding what did not work for the production of bluegill. First, no bluegill were produced when more than 10 adults were present in the 600 L tanks. Also, the authors attempted production in 80 L tanks and no spawning occurred in these tanks.

The methods of Bryan et al. (1994) were further refined by Mischke and Morris (1997). These authors collected fish outside of the typically spawning season (collected in fall). Initially, the authors held the fish at 22° C and a 16 h light/d photoperiod. After two months at these conditions, the temperature was reduced to 15°C and the photoperiod was adjusted to 8 h light/d. This adjustment occurred gradually over 2 wks. The fish were held at these conditions for 4 wks. Then, over a 2 wk period, temperature was increased to 25°C and photoperiod was adjusted to 14 h light/d. These

conditions were then maintained throughout the remainder of the trial. Using these methods, the authors were able to obtain fry from 40 spawns. Each spawn produced roughly 20,000 larvae. They also produced seven spawns of green sunfish x bluegill hybrids (10,000 larvae produced/spawn). Dudenhoeffer et al. (2012) mention the production of bluegill in a recirculating aquaculture system using a production procedure that is similar to what is described by Mischke and Morris (1997).

I have personal experience producing bluegill in a laboratory setting. For my research, I added fish (2 males and 3 females) to 1300 L circular tanks. Unlike the previously cited studies, my tanks were not flow-through. They did, however, receive aeration. The fish were fed to satiation three times per day using an artificial diet. The nesting boxes I used were also constructed using the bottoms of Rubbermaid buckets. I, however, did not press the gravel into silicone caulking. Instead, I just filled the nests with pea gravel. I established a total of 96 tanks of fish. I collected eggs from 35 of those tanks. Generally, the numbers of eggs released by the females was low (<1,000, never more than 3,000). The survival of the fry to 28 d age was low (~15%; fry fed on natural zooplankton population in tanks). My tanks sat outside and maintained ambient conditions. The fish spawned 1-2 d after a sudden increase in temperature (3-8°C increase in daytime high over 24 h period; spawned once high pressure conditions moved in after the passage of a cold front). I also attempted to spawn fish indoors using the temperature and photoperiod adjustments described by Mischke and Morris (1997) and had no success. In general, my personal feeling is that the tank culture methods that have been described in the literature work, but, the reward (i.e., number of fish produced) is low relative to the effort. It is likely that the controlled, indoor conditions described by Bryan et al. (1994) aided in their success. Still, I feel that pond culture of bluegill requires considerably less effort than tank culture and has the potential to produce many times more fish.

Resources Required to Produce 100,000 Fish

Pond culture:

A review of the literature has shown that on average, brood are stocked a density of 160 brood/ha (Table 1). The average number of fingerling recovered at this brood density is 337,000 individuals. Some of the studies did not provide detailed information regarding the size of fish recovered. It is likely that the average fingerling production shown in the table is inflated by density estimates of small fry. Not surprisingly, lower densities or larger (25-50 mm) fingerling were recovered. Based on the available information, it is estimated that 100,000, 25 mm TL fingerling could be produced using 100 brood fish stocked into one hectare of pond area. Considerable pond-to-pond variation in production has been observed (Oplinger, personal observation). Thus, splitting production across several smaller ponds would be advised.

Table 1: Summary of the literature on the pond production of bluegill. For each paper cited, the brood and fingerling production densities (#/ha) are provided. In addition, the size of the fish at stocking (when fingerling density was determined) is listed.

	Brood Density (#/ha)	Fingerling Production (#/ha)	Stocking Size	Source
	247	370,500	25 mm	Blosz (1948)
	74	123,000	660 fish/kg	Blosz (1948)
	198	676,780	"Small" (size not defined)	Surber (1948)
	200-300	400,000	Size not defined	Huet (1970)
	100	375,000	"Fry sized"	Higgenbotham et al. (1983)
	92.5	20,000-130,000	50 mm	Oplinger (Personal Observation)
Average	160	336,713		

Tank Culture:

Both Mischke and Morris (1997) and Oplinger (personal observation) provide data that can be used to estimate the numbers tanks and brood required to produce 100,000 fish. If data from both sources is averaged, it is estimated that 10,000 eggs are produced from each clutch and that 15% of the larvae survive to 25 mm TL. It is also estimated that eggs will only be recovered from 36% of the tanks. Given these parameters, a synopsis of the tank space and brood requirements is provided in Table 2.

Table 2: Numbers of tanks, nest trays, male brood, female brood, and spawns required to produce 100,000 bluegill in tanks. Data is shown under two scenarios: 1) when fish are stocked immediately after swim-up or 2) when fish are stocked after rearing to 25 mm TL.

	If Stocked as Larvae	If Stocked as 25 mm Fingerling
# of Spawns Needed	10	67
# of Tanks	36	240
# of Nest Trays	72	480
# of Male Brood	72	480
# of Female Brood	108	720

Largemouth Bass

Introduction

Largemouth bass *Micropterus salmoides* (LMB) are one of the most popular warmwater sport fish in North America. There are two recognized largemouth bass subspecies, the Florida bass and the

northern largemouth bass. The two subspecies can only be differentiated through genetic testing. Urban legend has it that the Florida bass grows larger than the northern largemouth bass. Research, however, has shown that the Florida bass performs poorly outside its native range (Philipp and Whitt 1991). As a consequence, the northern largemouth bass is the recommended subspecies at latitudes similar to Utah's (Philipp and Whitt 1991).

Largemouth bass share many reproductive life-history traits as bluegill. In the spring, male LMB construct nest in water that <1.5 m deep. Nests are typically constructed on hard substrates and near cover. Males use a sweeping motion with their tails to clear out debris. Nests typically have a diameter that is roughly double the length of the male that is constructing the nest. Unlike bluegill, LMB are solitary nesters. The LMB spawning season is shorter than that of bluegill. They typically spawn in early spring at temperatures of 18-24°C. The typical LMB spawning season lasts 4-6 wks. Females typically spawn with multiple males. Often, they release roughly half their eggs in the nest of the first male they spawn with. They then quickly find another nest and release roughly 25% of their eggs into that nest. Often, they will then wait approximately a month and will then release their remaining eggs into a third nest. Females typically contain 2000 eggs/kg of body weight. Males guard their nests after spawning and will protect the fry for up to 2 weeks after hatch. During this time, the fry stay close to the nest and school into "fry balls". Eggs typically hatch 2-4 d after deposition. Fry swim-up roughly 8 d after hatch and begin feeding on zooplankton and insects. Fish are added to the diet once they are roughly 50 mm total length. Cannibalism can be a problem when LMB are reared at high densities. Methods for limiting cannibalism will be discussed below.

Largemouth bass are reared in a pond setting. There are a number of different rearing "programs" used. These "programs" will be discussed below. These "programs" vary in cost and required manpower. Also, the desired stocking size is a factor that needs to be considered when selecting a "program". More labor intensive programs typically produce consistent, high fish yields. Less intensive programs are less consistent, but can at times produce significant numbers of fish.

Culture Methods

Largemouth bass have been produced by allowing fish to spawn naturally in ponds or through the hand-stripping of gametes. The hand-stripping of gametes has only been documented in research applications where small numbers of eggs are required. Large scale production of LMB occurs in ponds and will be the focus of this discussion. When LMB are allowed to naturally spawn in a pond, brood are typically maintained in a hatchery, but can also be collected from the wild (Heidinger 2000). Largemouth bass typically begin to mature at roughly 250 mm TL (10 inches). Most hatcheries use LMB that are 0.7 - 1.8 kg (1.5 - 4.0 lbs) in weight. Females that are 300-450 mm TL are sexually mature and there is evidence that they spawn more consistently than smaller or larger females (Davis and Lock 1997). Size appears to be more important in determining the maturation of LMB than age (Williamson et al. 1993). It is difficult to sex LMB. Sexing is best done prior in the spring, just prior to the spawn. At this time, females have a distended abdomen and a red, swollen vent. The males may emit sperm. Inserting a small tube into the vent and looking for the presence of eggs or sperm can be a reliable method for sexing LMB (Heidinger 2000). If it is not spawning season, it is best to observe the shape of

the scaleless area around the urogenital opening. This region is often circular in males and elliptical in females (Heidinger 2000).

Prior to spawning, ponds are thoroughly dried and then re-filled. Pond fertilization is usually necessary. Often, spawning sites are pre-formed by adding gravel to select sites in the pond. These artificial nests should be placed at least 2 m apart (Williamson et al. 1993). Fish are typically added at a 2:1 or 3:1 (male to female) sex ratio (Williamson et al. 1993). The number of males added should not exceed the number of available artificial nesting sites (if added; Williamson et al. 1993). Adults are typically added into ponds at a density of 25-100 fish/ha (Heidinger 2000). Fish should be added prior to the spawning season. Brood fish can be fed forage fish at a rate of 3 kg of forage/kg of LMB (for maintenance) and up to 11 kg of forage/kg of LMB (for growth; Heidinger 2000). Artificial floating feeds (minimum 40% protein content) can be provided at rates of 1-3% body weight/d (lower percentages used during cooler months; Williamson et al. 1993). Largemouth bass must be trained to accept artificial feed. It is not likely that wild brood will accept artificial feeds (Williamson et al. 1993). In a culture setting, the feed type (natural vs. artificial) has little effect on LMB gonad development and fecundity (Snow and Maxwell 1970). More details on artificial feed training of LMB are provided below.

The simplest method of fry production involves allowing the fry to remain in the ponds with the brood fish. While simple, the production observed using this method is variable, ranging between 500 and 100,000 fry produced/ha (based on harvest 20-40 d after hatch; Heidinger 2000). After the fry leave the nest, they can be susceptible to predation by the parents. This method is most frequently used in situations where pond space is limited and the fish are stocked at a small size (25-50 mm TL; 30-50 days after hatch). If pond space is limited and the fish are reared for a longer period of time, the adults can be removed by angling (Oplinger, personal observation).

When a larger stocking size is desired, more labor-intensive approaches are often used. One common approach is to transfer the fry to grow-out ponds. To do this, the fry balls are targeted using a seine and the fry are transferred to fishless ponds (this done 1-2 wks after hatch; Heidinger 2000). This is most feasible when water clarity is good. Often, the seining is performed from inside a boat. This limits sediment disruption and improves visibility. After capture, the fry are stocked into a fish-less pond at a rate of 120,000-180,000 fry/ha. The ponds are fertilized and the fish consume natural prey.

The most intensive method of LMB culture is also the most effective method for producing high densities of 6-8 inch fish (Heidinger 2000). To do this, the fish are typically trained to accept artificial feed. Bass are initially spawned in ponds and when they are 1-1.5 inches long they are transferred to oxygenated tanks or raceways at a density of 3-10 fingerling/L. For the first week after addition to the tanks or raceways, the fish are provided frequent (every 5-10 min) feedings of fish, fish-eggs or freeze-dried krill (Heidinger 2000). The goal is to get the fish used to frequent human interaction. After 7 d, they are transferred to a salmon diet (>40% protein content; 1.0-2.5 mm size pellet). They are fed the salmon diet at least 8 times/day at 15% initial body weight for 7 d/week (Williamson et al. 1993). Because of the high feeding rate, the tanks must be cleaned frequently. They are fed this diet until at least 50% of the fish have begun accepting the artificial food. After that, the fish are graded and cannibals and non-feeders are removed. They are then stocked into ponds at a rate of 6,000-24,000

fish/ha (Williamson et al. 1993; Heidinger 2000). Floating mats (1.5 x 1.5 m wooden frames with dark plastic) are placed into the ponds. The fry congregate near these mats. Food should be placed near the mats. For the first 10 d after stocking, the fish are fed 4 times/day with 2-3 mm diameter floating pellets at 15% of stocked biomass/d. The floating mats are then removed and for the next 20 d, they are fed at 10% initial biomass. After that, the fish are fed at 5% initial biomass (Williamson et al. 1993).

Most LMB producers opt to transfer the fry into ponds for growout (Davis and Lock 1997). Fry are seldom trained to accept artificial feed unless larger fingerling are desired (Davis and Lock 1997). Most LMB are stocked into the wild at < 50 mm TL. Regardless of the rearing method, fish are removed from the ponds by either seining or pond draining. LMB are best hauled in a saline solution (0.3-1.0% sodium chloride; Williamson et al. 1993). Water temperatures during transport are often cooled to ~16°C. Fry are often transported in oxygenated plastic bags at densities of 2,000-12,000 fry/L of water. Larger LMB (200 g) can be hauled in oxygen supplemented tanks at densities up to 180 g/L (Williamson et al. 1993).

As previously mentioned, the hand-stripping of LMB gametes has been used to produce small groups of fish for research purposes. Texas Parks and Wildlife produces a small number of triploid LMB annually using hand-stripped gametes (Garrett et al. 1992). To induce spermination or ovulation, captive brood fish are injected with human chorionic gonadotropin (hCG) at a rate of 4,000 IU/kg. After ovulation, eggs are stripped into Petri dishes and sperm is added. Garrett et al. (1992) was able to induce triploidy in 100% of fry that were subjected to hydrostatic pressure at 8,000 psi for one minute, with the treatment starting 5 min after fertilization.

Resources Required to Produce 100,000 Fish

Williamson et al. (1993) provides guidelines for the pond surface area and brood numbers required to produce LMB fingerling of various sizes (See Table 4 in Williamson et al. 1993). Table 3 (below) shows the data from Williamson et al. (1993). It is assumed that the fish will be spawned in a pond and that the fry will be transferred to a separate pond for growout. The data has been extrapolated from Williamson et al. (1993) on the assumption that 100,000 fingerling are desired.

Smallmouth Bass

Introduction

Smallmouth bass *Micropterus dolomieu* (SMB) are another sport fish that have been successfully cultured. In Utah, SMB are found in Flaming Gorge, Lake Powell, Starvation Reservoir, and the Uinta and Sevier Rivers (Sigler and Sigler 1996). They are less tolerant of warm water and turbid conditions than LMB. The reproductive ecology of SMB is similar to the LMB, but, some key differences exist. Spawning occurs at water temperatures of 16.1-18.3°C (Sigler and Sigler 1996). Males build nests of 0.3-1.8 m in diameter in 0.6-6.1 m of water. SMB prefer to nest in rockier substrates than LMB (Sigler and Sigler 1996). The typical female produces approximately 3,000 eggs/kg of body weight. The eggs take 9.5 d to hatch at 12.8°C and 2.25 d at 23.9°C (Sigler and Sigler 1996). Similar to LMB, recently hatched SMB fry form "fry balls" that are guarded by the male. After the yolk sac is absorbed, fry feed on zooplankton and small midge larvae. They become piscivorous at approximately 40 mm TL and begin feeding on

Table 3: Estimated pond surface area (for fry production and fingerling rearing) and brood fish requirements for producing 100,000 largemouth bass at stocking sizes ranging between 25 and 102 mm. Data based on Table 4 from Williamson et al. (1993).

Desired Size at Stocking (mm)	Spawning Pond Surface Area Required (ha)	Broodfish Required (kg)	# of Fry Transferred	Fingerling Pond Rearing Area Required (ha)
25	0.6	79.6	138,947	0.7
32	0.7	101.0	176,666	1.0
38	0.9	132.0	230,588	1.5
44	1.3	177.3	312,500	2.5
51	1.8	251.4	443,556	4.4
64	3.8	539.7	946,154	15.1
76	8.8	1255.8	2,203,636	58.7
102	16.0	2272.0	4,000,000	160.0

crayfish at 80 mm TL. When available, crayfish can constitute a significant proportion of the SMB diet (Sigler and Sigler 1996). The production of sterile triploid SMB has not been documented.

Culture Methods

Information regarding the methods for culturing SMB are somewhat limited. Many of the methods, however, are similar to what are used for LMB. Two culture methods for SMB have been described. The first is a pond method. Broodfish are stocked at a density of 225 kg/ha (added to ponds when consistently >16°C). They are fed baitfish at a rate of 7.2 kg/kg of brood. Portable nest boxes are placed inside the ponds. The nests consist of two boxes that sit inside each other. The outer box is 53.5 x 53.5 cm and has a fiberglass window screen bottom. The inner box is 50.8 x 50.8 cm and has a 0.6 cm mesh-hardware cloth bottom (Williamson et al. 1993). The nests are filled with rocks (5-10 cm diameter). The nests are placed into ponds at 45-60 cm of depth and are spaced 3-4 m apart. The number of males added to the pond should equal the number of nesting boxes. One third more females are added (Williamson et al. 1993). The boxes are observed daily using an under-water viewing scope (constructed with PVC pipe). Once the eggs appear, they are observed daily until they disappear (indicative of hatch). They continue to be observed until black fry are seen on the rocks. At this time, the inner box is gently removed capturing the fry in the outer box. The fry are then stocked into rearing ponds at a density of 125,000-187,500 fry/ha (Williamson et al. 1993). Initially they are stocked into the outer boxes of the nest boxes. Once free swimming, these outer boxes are removed. The fry feed on natural prey until harvest.

The second method of SMB culture is more intensive. Brood fish are added to concrete raceways 2-3 weeks prior to the normal spawning time (density not specified; Williamson et al. 1993).

Wooden nests (40.6 x 10.6 x 10 cm; 0.32 cm hardware cloth covering bottom) are filled with 2.5-7.6 cm rocks and are placed into the raceways. The presence of eggs is checked daily. After spawning, the nests and eggs are removed from the raceways. They can either be incubated in an indoor catfish rearing facility (with moving paddles) or in fry rearing troughs at 23°C. Ample circulation is provided to prevent the fry from aggregating. Vinyl coated wire mesh (1.9 cm x 1.9 cm) is placed on the bottom of the troughs. This mesh helps ensure that the fry are evenly distributed throughout the troughs (Williamson et al. 1993).

Limited information regarding the hauling of smallmouth bass is available. It is assumed that the densities and hauling conditions used for LMB are also adequate for SMB. Carmichael et al. 1983 noted that survival during hauling increases if SMB are hauled in 0.3-1.0% sodium chloride solution.

Resources Required to Produce 100,000 Fish

Little information regarding culture techniques for SMB is available in the literature. Hatch, survival, and growth rates have not been reported. As a result, it is not possible to determine the resources required to produce 100,000. It is assumed, however, that the resources required for SMB production are similar to those for LMB.

Crappie

Introduction

There are two species of crappie; white *Pomoxis annularis* and black *Pomoxis nigromaculatus*. Generally, the two species can be separated by the number of spines on their dorsal fins (six for white crappie, 7 or 8 for black). The black crappie is widely distributed throughout Utah. Within the state, the white crappie is only found in Gunnison Bend Reservoir (Sigler and Sigler 1996). Both species are opportunistic feeders. They feed primarily on invertebrates but can also consume fish. The reproductive habits of both species are similar. They spawn in early spring when water temperatures are 14-22°C (maximum spawning temperature for black crappie is 18°C; Sigler and Sigler 1996). Males of both species construct nests near submerged vegetation or tree roots and court females to deposit eggs within their nests. The eggs hatch in 3-5 d at 16°C. The males guard the fry for a few days after hatch.

Crappie are a popular sportfish. They can be difficult to manage because they are prone to over-population in smaller ponds (Buck and Hooe 1986). When over-populated, they exhibited stunted growth (Buck and Hooe 1986). They can also consume large numbers of LMB fry and fingerling (Buck and Hooe 1986). The production of hybrid crappie has been proposed as an alternative. Hybrid crappie have lower survival than purebred black or white crappie. This lower survival prevents over population and helps maintain a "desirable" size structure. F_1 generation hybrids also demonstrate greater growth than purebred crappie (Hooe and Buck 1991). The stocking of hybrid crappie should be performed with caution, however. Epifanio et al. (1999) tested the production of F_1 and F_2 generation crappie. The authors found that the F_1 generation is viable and capable of producing offspring, albeit, the numbers produced are less than those of purebred crappie. The F_1 generation can successfully back-cross with both parent species. The resulting offspring are reproductively viable. The F_2 generation is also viable, however, it appears that the reproductive success of this generation is reduced by pre- and post-zygotic

barriers (Epifanio et al. 1999). These results indicate that the stocking of hybrid crappie may be effective (e.g., limited over-population risk) in situations where no other crappie are present (e.g., in new farm ponds). Since F_1 generation crappie can backcross with the parent species, the stocking of these fish is not recommended in situations where either parent species could be present. Studies in Illinois have tested the stocking of F_1 crappie in lakes that lack crappie. Recruitment among these stocked fish was not detected, suggesting that the stocking of F_1 individuals can help prevent over-population (Hooe and Buck 1991). The induction of triploidy is another method of limiting reproduction by crappie. Baldwin et al. (1990) hand-stripped white crappie gametes and subjected them to a cold shock (5°C for 60 min, starting 5 min post-fertilization). This research was experimental and achieved a triploidy rate of 72-92% (Baldwin et al. 1990). Triploid hybrid crappie (white crappie female x black crappie male) have been produced using similar methodology (Parsons and Meals 1997).

Culture Methods

Little research on methods of crappie culture has been conducted. Generally when large numbers of crappie are desired, they are allowed to reproduce naturally in ponds. The hand-stripping of gametes has been documeted (e.g., Baldwin et al. 1990) but has only been used in research applications. The most frequently cited crappie culture paper is Smeltzer and Flickinger (1991). In this paper, crappie brood (>250 mm TL) were stocked at a density of 100-125 fish/ha and at a sex ratio of 1:1. Male black crappie are darker in color than female black crappie (Smeltzer and Flickinger 1991). Males of both crappie species have a round or oval scaleless area around the urogenital pore. In females, this region is pear or teardrop shaped. Smeltzer and Flickinger (1991) collected brood from the wild and added them to the production ponds a few weeks before the anticipated spawn. In contrast, other studies have suggested that it is beneficial to add brood to ponds in the fall prior to the spawn (Siefert 1968). Crappie production is variable (0-165,000 fish/ha; Smeltzer and Flickinger 1991). Generally, crappie are harvested from the ponds by seines and stocked as fry (Smeltzer and Flickinger 1991). The removal of crappie from culture ponds can cause high mortality. Smeltzer and Flickinger (1991) found that 76% of fry died when seined during the day. Mortality dropped to 8% when seined at night. The hauling of fry in physiologically saline solutions does not reduce mortality (Smeltzer and Flickinger 1991). Black crappie also have been reared to fingerling size (25-100 mm TL). If this larger fingerling size is desired, it is recommended that ponds are fertilized (Smeltzer and Flickinger 1991; Myers and Rowe 2001). Alternatively, fingerling can be trained to accept artificial feed using a training regime that is similar to what is used for LMB (Smeltzer and Flickinger 1991).

Hybrid crappie are easier to produce than other hybrid species (Martin 1988). Black and white crappie readily hybridize. Most often, hybrids are produced by controlling the species added to the brood ponds (i.e., add female white crappie with male black crappie, or vice versa). Hybrids can be produced in both directions, so, it does not matter which species serves as the male and which serves as the female. Hybrids have also been produced by hand stripping gametes with subsequent egg incubation in vertical stack incubators (water temperature = 18°C; Hooe and Buck 1991). The fertilization and hatching success of this method was not noted.

Resources Required to Produce 100,000 Fish

Smeltzer and Flickinger (1991) described the production of black crappie in 0.04 ha ponds. They tested a broad range of brood densities (100-250/ha) and sex ratios (1:1, 2:3. 3:2, and 3:1; female to male). Regardless of the treatment conditions tested, they noted extreme variation in fingerling production (0-164,700/ha). They had best success stocking brood at a 1:1 sex ratio at a density of 100/ha. Their average fingerling yield under these conditions was 69,729/ha (range: 50-139,407/ha). Based on this information, it is estimated that 71 male and 71 female brood and a total pond surface area of 1.43 ha is required to produced 100,000 fingerling (~50 mm TL). Since crappie production is extremely variable, it is advised that this production is split across several ponds. There is not sufficient information in the literature to estimate the resources required to produce 100,000 white or hybrid crappie.

Walleye and Saugeye

Introduction

Walleye *Sander vitreus* are one of the most popular sport-fish in the North America. They are particularly popular in the Midwest. They are native to that portion of the country but have been widely stocked outside their native range. Walleye occupy a wide range of temperatures (0-30°C), but, their preferred temperature is 20-23°C (Nickum and Stickney 1993). They are negatively phototaxic and spend much of the daylight period either on the bottom of a lake or hiding under structure. They feed primarily on other fish. Generally males mature at 2-4 years of age and females mature at 3-6 years of age. Walleye spawn in the spring when temperatures reach 7.2-10.0°C (Nickum and Stickney 1993). They spawn in shallow water and their eggs and sperm are broadcasted into the water column. The eggs are adhesive and stick to the substrate after sinking. This adhesiveness is lost after the eggs water harden (takes approximately 4 hrs). The eggs hatch in about 10 d at temperatures of 12.8°C and 4 d at 23.9°C (Nickum and Stickney 1993). Walleye do not provide any parental care. Walleye were first introduced into Utah in 1951 and are now found in Willard Bay, Gunnison Bend Reservoir, Dmad Reservoir, Starvation Reservoir, Utah Lake, the Weber River, and Lake Powell (Sigler and Sigler 1996).

Culture Methods

Culture methods for walleye are well established and similar methods have been used for nearly 100 years (Nickum and Stickney 1993). Walleye eggs are rumored to be easy to collect and incubate. Hatch rates for walleye eggs can be similar to what is observed for hatchery reared trout (>70% hatch). The majority of agencies collect walleye eggs from wild brood (Nickum and Stickney 1993). Brood are typically collected in trap nets. The eggs are fertilized in the field and after water hardening, they are transported to a hatchery for incubation. Generally, eggs from a single female are fertilized using sperm from two males. Fertilization rates can drastically decrease with increasing egg volume (Moore 1997). As a result, females are fertilized individually rather than in pools (Moore 1997). Walleye eggs are highly adhesive. Immediately after the post-fertilization rinse, eggs are typically treated with a 400 mg/L tannic acid solution for 2-3 min (Nickum and Stickney 1993). The eggs are continuously stirred with a feather during this treatment. Eggs are typically incubated in jars (eggs from several females pooled

into each jar). Flows in these jars should be enough to maintain a gentle "roll". Incubation temperatures range between 10 and 20°C (Nickum and Stickney 1993). Depending on temperature, eggs will generally hatch in 1-3 wks. Most agencies start egg incubation at 10°C and increase the temperature by 0.5°C/d until 16°C (Malison et al. 1990). Many agencies release brood that do not provide free-flowing eggs or express sperm. Some agencies, however, will transport fish that are close to spawning (within a few days) into a hatchery and will hold them in tanks until they provide eggs. On occasion, walleye have been produced using a captive brood. To produce a captive brood, Hearn (1980) reared walleye fry in 3.0 ha ponds until maturation (3-6 years). Eggs were produced from these fish after injection with human chorionic gonadotropin (hCG). Fish were provided an interperitoneal injection at a rate of 220 IU/kg (not necessary for males) and were held in ~2,000 L tanks in a hatchery building. The fish were checked every 12 hours. Females that did not produce eggs within 5 days were given a second injection (90% of fish responded to first injection). Initially, the tanks were 10°C, but the temperature was gradually increased to 13°C over 3 d (Hearn 1980). Dabrowski et al. (2000) produced an out-of-season spawn in walleye through a series of temperature and photoperiod adjustments. The females used in their experiment were provided hCG at 150 IU/kg followed 35 hrs later with a second injection that was 500 IU/kg. Malison et al. (1998) also produced an out-of-season spawn. To do this, they captured 100 walleye brood in the fall. These brood were separated by sex and held over-winter in 0.07 ha ponds. Starting 3-10 weeks before wild fish normally spawn, the brood were transferred to indoor tanks (750 L volume; 3-5 females and 1-2 males in each tank). Over a 7 day period, the temperatures in the tank were raised from 2°C until reaching 10°C. Photoperiod was maintained at 12:12 (hours of light:hours of dark/day). The females were given an intramuscular injection of hCG on days 0 (after reaching 10°C; 150 IU/kg) and 2 (500 IU/kg). Between 60-100% of the females ovulated within 9 d of injection. The males were given a single injection of hCG (150 IU/kg) on day 0.

After hatch, walleye fry can be raised in both ponds or tanks. Methods for the intensive tank culture of walleye fry are still under development (as discussed later). Walleye fry survive better when raised in ponds than in tanks. The downside of pond culture is that the fingerling can be difficult to harvest and fingerling >75 mm TL perform best when fed bait fish. Most agencies fertilize ponds to promote zooplankton growth and stock their ponds with 1-2 d old walleye fry. Pond fertilization protocols vary by hatchery. This variation in protocol exists because conditions (temperature, pH, alkalinity, etc.) vary by hatchery. Most hatcheries have developed their protocols through many years of "trial and error". Fingerling are typically raised in the ponds for approximately one month and are then stocked when they reach 40-50 mm TL (Summerfelt et al. 1996). The fry are recovered for stocking by either pond seining, the setting of fyke nets, or pond draining. Survival during the first month in a pond varies from 10-75%. Research has shown that fertilization regimens that maximize zooplankton production also maximize fish survival and growth (Summerfelt et al. 1996).

Typically, hatcheries alter their rearing strategies if larger fingerling (>50 mm TL) are desired. These altered rearing strategies are required because it is difficult to maintain adequate forage for larger fingerling in ponds. As a result, cannibalism can be common among these larger fingerling (Kuipers and Summerfelt 1994). There are two larger fingerling rearing strategies. Both require fry to be reared in ponds as previously described. Then, changes in the rearing strategy occur when the fingerling reach 40-50 mm TL. For the first strategy, fingerling are moved from ponds into raceways and are fed a

formulated diet. This strategy requires that fingerling are trained to accept artificial feed. The Iowa Department of Natural Resources performs this training by feeding fingerling every 10 minutes using an automated feeder. The fingerling are fed at 5% body mass/d for the first five days, then at 6% for days 6-8, 6.5% on days 9-11, and then 7% thereafter (Muhm 2005). Fish are fed Nelson and Sons Walleye Grower 9206 or Walleye Grower 0401 (Muhm 2005). They are stocked when they reach ~ 180 mm TL (in late summer/early fall). In Minnesota, fingerling are collected from ponds and are placed in raceways at 20°C. They are fed for the first 7 d with Kyowa C-1700. On days 8-14 they are fed Kyowa C-2700. Then, from days 15-35 they are fed Biodry 4000 (Minnesota Sea Grant 2010). Regardless of diet, the fish are fed with automatic feeders at a rate of 10% body mass/d. After feed training, the fish are placed in cages that are submerged in ponds for growout (Minnesota Sea Grant 2010). They are fed Biodry 4000 when in the cages. Some agencies place the fish back in ponds and continue feeding them artificial feed after training. Since walleye feed most actively at dawn and dusk, most agencies maintain dim lighting during feed training. Also, to increase exposure to feed, long (~ 18 hr light : 6 hr dark) photoperiods are maintained during training. During feed training, walleye perform best on a high (55-60%) protein diet (Barrows et al. 1988). After training, the protein content of the diet can be decreased to ~40% (Barrows et al. 1988). It appears that that artificial walleye diets are still under development and that this is an active area of research. Thus, it is possible that better diets than what is listed here exist. A second common method of rearing larger fingerling involves leaving the fingerling in ponds. Once 40-50 mm TL, fry densities are adjusted to ~25,000/ha and are fed minnows. This method is commonly used, however, details about the numbers of minnows fed have been poorly described (Summerfelt et al. 1996).

More intensive culture methods have also been applied for walleye. These intensive techniques allow all aspects of rearing, from hatch to stocking, to occur inside a hatchery. These techniques do not require the pond rearing of fry. This is appealing where pond space is limited. Intensive fry rearing techniques, however, are still under development and typically produce lower survival (often < 10%) compared to pond rearing. This poor survival has been attributed to low rates of swim bladder inflation and low acceptance of artificial feed when swim-up occurs in tanks (Peterson et al. 1997). Research has not identified the mechanisms that underlie these problems. Cannibalism can also be a major issue when intensively cultured (Peterson et al. 1997). The period where these issues are most problematic are the first month after hatch (Peterson et al. 1997). Most hatcheries rely on pond rearing during the first month after hatch because it alleviates these issues. The intensive culture of walleye fry requires the use of circular tanks. Manifolds are used to create an upwelling flow (necessary because fry tend to congregate on bottom of tanks). The inflow occurs at the bottom of the tanks and a large surface area screen (made of 500-700 µm mesh) is fitted to the standpipe at the top of the tank. The large surface area of the screen minimizes water velocity and helps prevent the fry from becoming trapped against the screen. Walleye fry are phototaxic (in contrast to adults). Bright lights are used to keep the fry off the bottom. The fry tend to congregate around the edges of the tanks, however, which limits their ability to find food. Often, black plastic is used to shade the edges of the tanks, which keeps the fry away from these edges. Fry are typically raised at temperatures of 17-24°C. Fry can be reared at densities as high as 1000/L. Cannibalism can be high at these densities. As a result, significantly lower (4-5/L) rearing densities are recommeded (Krise and Meade 1986). Often, the fry are provided 18-24 h

of light/d during the first 1-2 wks after hatch. The State of New York produces walleye in raceways that are similar to what are used for trout. The fry are initially reared on brine shrimp nauplii and are converted to an artificial diet during days 30-50 post-hatch (Aneshansley et al. 2001). Recent research has also shown that walleye can be reared from hatch in a recirculating aquaculture system (Zarnoch et al. 2010). In this recirculating system, walleye were reared to 270 mm TL in 240 d.

Feed acceptance is the greatest challenge in the intensive culture of walleye (Peterson et al. 1997). Swim-up fry are often reluctant to take artificial feed. Artificial feed, however, is cheaper and can be provided more predictably than live feed. A variety of feeding strategies have been employed. Larval walleye typically begin feeding at around 90 temperature units (a temperature unit is the number of degrees centigrade experienced for 24 h). Barrows et al. (1988) found that fry grew better on decapsulated brine shrimp cysts than on an artificial Biotrainer diet. Swim bladder inflation rates, however were higher among individuals fed the Biotrainer diet. Peterson et al. (1997) successfully reared walleye fry until 23 d age on brine shrimp nauplii. The nauplii were produced by incubating cysts for 22 h at 28°C in a 5.2% salt solution. In contrast, Krise and Meade (1986) speculated that poor food uptake by fry was related to the size of brine shrimp nauplii. In their opinion, the nauplii are too large for larval walleye. They suggest feeding zooplankton for the first three days after hatch and then adding brine shrimp nauplii. The size of the brine shrimp can be increased as the fish age (Krise and Meade 1986). Krise and Meade (1986) also provide suggested feed quantities for walleye fry (see Table 4 of their paper). In contrast, Loadman et al. (1989) fed larval walleye an artificial diet. For the first 10 d after hatch, Kyowa B400 was provided. After that, the fry were switched to Kyowa B700 feed. Cannibalism can be a significant problem during feed training. Cannibals are separated from the rest of the fish regularly. The critical period where culturists are concerned about feed acceptance and swim bladder inflation typically lasts 20-30 d. After this critical period, walleye can be reared using previously described methods (in ponds or continued intensive culture).

Saugeye are produced by crossing female walleye with male sauger. This hybrid is not sterile and therefore, viable eggs and fry can be produced when saugeye are crossed with male sauger (Siegwarth and Summerfelt 1990). When saugeye are produced, brood are often collected from the field and are transported to a hatchery where gametes are stripped and eggs are fertilized and incubated. Alternatively, sauger sperm can be collected in the field and placed on an extender. The optimal sperm extender for sauger contains: 0.234 g calcium chloride dihydrate + 0.264 g magnesium chloride + 0.472 sodium phosphate dibase + 3.744 g potassium chloride + 13.155 sodium chloride + 20.000 g glucose + 0.200 g citric acid monohydrate + 40 mL of sodium hydroxide (mixed at 1.27 g/100 mL water) + 40 mL bicine (mixed at 5.3 g/100 mL water) + 180 µg ampicillin + 1,920 mL water (Moore 1987). The Colorado Division of Wildlife tested this extender and recommend mixing sperm and extender at a 1:2 ratio (sperm : extender; Satterfield and Flickinger 1995). They also recommend the addition of 24 mL of extended sperm into 11.4 x 10.8 cm sandwich storage containers (Satterfield and Flickinger 1995). The extended sperm can be stored refrigerated for at least 3 days using this extender (Satterfield and Flickinger 1995). After fertilization, eggs can be incubated and fry can be reared using methods similar to what was previously described for walleye. Due to sterility concerns, triploid saugeye are often produced. Garcia-Abiado et al. (2001) tested a variety of triploid induction methods

and found the method of triploid saugeye production was a 9,000 psi pressure shock that lasts 12 min and is initiated 4 min after fertilization.

Resources Required to Produce 100,000 Fish

Malison et al. (1990) and Nickum and Stickney (1993) provided average percent hatch and survival rates for various stages of walleye. In addition, these authors provide information on the average egg yield for female walleye and guidelines McDonald jar, tank, and pond loading rates. This information is compiled in Table 4 (below), which shows the resources required to produce 100,000 walleye under a number of scenarios. The table shows the resources required to raise walleye until 30, 70, or 100 mm in ponds or in tanks. For the purposes of the table, it was assumed that fish that were reared in ponds until 100 mm were moved into a hatchery after 50 d for artificial feed training. These fish were then re-stocked into ponds.

Channel Catfish

Introduction

Channel catfish are one of the most popular sportfish in North America. They are easily raised in hatcheries, have been cultured for many years, and are stocked throughout the country. As a result, methods for culturing channel catfish are well described. Channel catfish are native to the eastern two-thirds of North America and were introduced into Utah in 1888 (Sigler and Sigler 1996). Juvenile channel catfish feed primarily on invertebrates (Sigler and Sigler 1996). Adults are more omnivorous consuming invertebrates, detritus, plant material, and other fish (Sigler and Sigler 1996). Like most species of catfish, male channel catfish construct nests in protected areas such as under logs or in holes along the bank of a river (Sigler and Sigler 1996). They spawn at temperatures between 22 and 27°C (Sigler and Sigler 1996). At 27°C, eggs will hatch in approximately 7 d and fry absorb their yolk sacs 3-5 d after hatch (Sigler and Sigler 1996). One unique feature of channel catfish eggs is that there is a gelatinous protein matrix that binds the eggs together into a single mass.

Culture Methods

Many options for culturing channel catfish exist. Most producers maintain a captive brood and allow spawning to occur "naturally" in ponds (Busch 1985). Eggs can then either be hatched in the pond and reared in sympatry with the parents or can be moved into a hatchery where they are incubated in troughs or eyeing jars. A third option is to allow the eggs to be reared by the male until 1 d after hatch. At this point, the sac fry are transferred to another pond where they are reared in the absence of the brood. Most producers maintain a captive brood. Brood fish are held in "brood ponds" and are added to the "spawn ponds" in early spring. A fourth option is to hand-strip gametes from catfish. This is typically done for research purposes and is seldom done when large numbers of fish are produced. One advantage of hand-stripping, however, is that triploidy can be induced by using a cold shock (5°C for 60 min, starting 5 min after fertilization; Wolters et al. 1981). It has been recommended that brood fish are fed a ≥36% protein diet at a 1% body mass/d ration three times a week when water temperatures are 13-21°C (Busch 1985). They should be fed 2% body mass/d ration four times a week at temperatures ≥22°C. Channel catfish are not fed at temperatures <13°C.

Table 4: Estimated resources (pond area and number of eggs, eyeing jars, brood, and tanks) required to rear walleye to either 30, 70, or 100 mm total length. Data derived from estimates provided in Malison et al. (1990) and Nickum and Stickney (1993).

	30 mm in Ponds[a]	30 mm in Tanks[b]	70 mm in Ponds[c]	70 mm in Tanks[d]	100 mm in Ponds[e]	100 mm in Tanks[f]	Assumptions
Total # Eggs Required	400,000	1,000,000	457,000	3,200,000	703,000	5,333,333	62.5% median hatch rate
Mass of Females Required to Produce Eggs (kg)	6.7	16.7	7.6	53.3	11.7	88.9	60,000 eggs produced/kg
# of McDonald Jars Required	12	31	14	99	22	164	32,500 eggs/jar
Pond Surface Area Required (ha)	1.0	N/A	1.1	N/A	1.8	N/A	250,000/ha initially added
# 2 m Diameter Circular Tanks Required	N/A	4	N/A	10	44[g]	27	200,000 swim-up fry initially added

[a]40% survival assumed

[b]16% survival assumed

[c]35% survival assumed

[d]5% survival assumed

[e]35% survival until feed training in tanks and 65% survival in ponds after training assumed

[f]3% survival assumed

[g]Based on 3,500 fish/tank, as suggested by Malison et al. (1990) during feed training

Spawning ponds must contain cavities where male channel catfish can construct nests. Objects that mimic natural spawning cavities (e.g., milk cans, drain tiles, wood boxes, earthen crocks, pieces of pipe) are placed in shallow water (0.25-0.75 m) throughout a pond (Stickney 1993). Brood fish are added to "spawning ponds" at densities high as 1,200 fish/ha. Most hatcheries, however prefer a brood density of about 400 fish/ha (Steeby and Avery 2005). It appears that sex ratio has little effect on channel catfish production and ratios of 1:1 to 1:4 (male : female) are often used (Stickney 1993). Most hatcheries simply add fish to ponds and let them spawn. Some hatcheries will attempt to control the genetics of the young by pairing brood. When this is done, cages (approximately 1.5 m wide x 3 m long) are constructed along the shore of the ponds using fencing material. An artificial spawning cavity is placed inside each cage and the desired brood fish are then added (Stickney 1993). Regardless of spawning method (paired vs. random mating), containers are typically checked once every 24-72 h and the egg masses are collected and brought into the hatchery. Once in the hatchery, they are disinfected using a 10-15 min treatment with a 100 mg/L iodine solution. Some hatcheries simply leave the egg masses in the ponds and rear the fry in sympatry with the brood.

If a hatchery opts to remove the eggs from the spawning ponds, they are typically incubated in specially designed hatching troughs. These troughs are conventional troughs that have been retrofitted to have plastic paddles that rotate at 20-25 rpm (Steeby et al. 2004). Individual egg masses are placed into coated wire mesh baskets (Steeby and Avery 2005; ~20 x 20 cm; ~8 cm deep; 6.3 mm mesh; 6-8 baskets/trough). The baskets are suspended off the bottom so the fry fall through after hatch. Airstones provide an effective alternative to paddles if the stream of bubbles does not travel directly through a mass of eggs (Steeby and Avery 2005). Jar incubation of eggs is also possible. The biggest limitation with jar incubation, however, is that the eggs are prone to fungal infection. The prevalence of fungus can be greatly reduced by treating the eggs with a 1.5% sodium sulfite (Na_2SO_3) solution (Ringle et al. 1992). The solution is applied at a rate of 1 L/500 g of eggs and the eggs are slowly stirred during treatment. The treatment lasts until the gelatinous matrix has dissolved. After the matrix has dissolved, the eggs can be added to jars at a density of 80-1,200 mL eggs/jar. Flows in the jars should be set so the uppermost layer of eggs barely rolls (Ringle et al. 1992).

The yolk sac will be absorbed and fry will begin to accept feed roughly one week after hatch Swim-up fry can be offered either catfish or trout starter feed. It is best to initially provide a feed with >50% protein content (Busch 1985). The fry should readily accept the feed and high percentage of fish should be consuming the feed within one to two weeks after swim-up. Once the fry readily accept the feed, they can be transferred to a pond or tank for grow-out. If ponds are used, fry are typically stocked at a density of 125,000-625,000/ha (Stickney 1993). Initially, feed should be provided at a daily rate of 11-25 kg/ha. Fish should be fed in 3 h intervals. Once the fish reach 1.5 cm, a #1 crumble diet is provided at 3-4% body mass/d. Most producers do not weigh out feed. Instead, they feed the fish ad-libitum (Stickney 1993). Feed size should be increased accordingly as the fish grow. Most producers use floating pellets because when the fish come to the surface to feed, it provides the producer an opportunity to observe overall growth and fish health. High fry densities (125,000-625,000/ha) are typically maintained during the first growing season. Fish are typically ~110 mm TL after this first growing season. If 200 mm TL fish are desired after the first growing season, initial stocking densities of

35,000-50,000/ha are recommended (Stickney 1993). If fish are held for a second growing season, it has been suggested that ponds are drained and that the fish are added to new ponds at a density of 2,000-20,000/ha (Stickney 1993).

Pond culture is the most common method for rearing channel catfish. Over the past couple of decades, alternative methods of catfish culture have been developed. Some commercial producers raise catfish in cages that are housed in ponds. Cage culture allows multiple groups (e.g., species, or size classes) to be reared in a common pond and is beneficial when pond space is limited. Often cage culture is used by small producers who maintain a minimal number of cages in public waters. Raceway culture of channel catfish has also been utilized. The primary limitation to this rearing strategy is that it is difficult to find wells or springs that produce an ample supply of water that is warm enough to be suited for channel catfish culture. As a result, raceways are primarily used by smaller producers. Another alternative are "in-pond" raceways. In pond raceways are structures that are designed to mimic raceways. Air lift pumps are used to supply water from the pond into the raceway. In pond raceways allow producers to rear catfish at higher densities than in cages. These raceways also allow producers to grow multiple groups of fish in the same pond. In-pond raceways can help alleviate the need of finding a water source with a temperature that is adequate for channel catfish production. A few commercial producers have begun using in-pond raceways over the past 10-15 years. Finally, recirculatling aquaculture have also been used for channel catfish production (Beleau 1985). Because of high construction and maintenance costs, recirculating facilities are primarily used for research purposes and are seldom used for large scale production.

Resources Required to Produce 100,000 Fish

Busch (1985) states that typical survival from egg to hatch is 80%. Also, the average female brood fish will produce approximately 13,200 eggs (Busch 1985). Approximately 50% of the females will spawn in a pond setting (Busch 1985). Finally, approximately 50% of fry will survive until the end of the first growing season. Given these facts, Busch (1985) estimates that 38-40 female brood are required to produce 100,000 fingerling. Typical sex ratios are 1:1 to 1:4 (male : female; Stickney 1993). Thus, at least 10 male brood will be required to produce this number of fingerling. The spawning pond required to produce this number of fry will be approximately 0.20 ha in area. Fry can be reared to fingerling in a 1.0 ha pond. Busch (1985) states that 200,000 eggs can be incubated in a single paddlewheel trough. Densities during the initial 2 week food training period should be 100,000/trough. Thus, two additional troughs for rearing sac fry will be required.

Wiper

Introduction

Striped bass *Morone saxatilis* are a popular sportfish. They are native to eastern North America. They are highly tolerant of highly salty conditions and are frequently found in estuaries. In the 1930's, states began to experiment with the stocking of striped bass into freshwater impoundments (Kerby 1993). The stocking of striped bass into freshwater habitats was met with mixed success. These stockings demonstrated that spending time in salt water was not a physiological requirement for

reproduction in striped bass. Still, striped bass did not reproduce in many systems where they were stocked. The white bass *Morone chrysops* is a closely related species. It is native to the Midwest and only lives in freshwater. The white bass obtains a smaller adult size than the striped bass and stunted growth is found in many populations (Kerby 1993). Wiper (also known as hybrid striped bass) are a cross between the striped bass and the white bass. They are produced because wiper are larger than white bass and have a fighting ability that is similar to that of striped bass. Wiper are better adapted to freshwater environments than striped bass (Kerby 1993). There are two wiper crosses: palmetto bass (striped bass female x white bass male) and sunshine bass (white bass female x striped bass male). Both crosses are considered desirable sportfish and have similar culture properties (e.g., survival, diet, etc.). Juvenile wiper feed primarily on zooplankton. Wiper become piscivorous as adults. Frequently, wiper are stocked to help control populations of gizzard shad *Dorosoma cepedianum*. Wiper are not sterile and often, triploid fish are produced by using either a pressure or a heat shock (Kerby and Harrell 1990). Within Utah, striped bass are only found in Lake Powell (Sigler and Sigler 1996). White bass are found in Utah Lake, the Jordan, Provo, Spanish Fork, and Sevier Rivers, and several reservoirs including Deer Creek and Gunnison Bend (Sigler and Sigler 1996). Wiper are found in several reservoirs including Willard Bay, Huntington North, Newcastle, Otter Creek, and Piute.

Culture Methods

Wiper have been successfully produced using both wild and captive brood. For example, the World's largest wiper producer, Keo Fish Farms has a captive brood for both species. The Colorado Division of Wildlife obtains sperm from striped bass in Texas, places that sperm on extender, and uses it to fertilize eggs from white bass that are from Colorado (Pat Martinez, U.S. Fish and Wildlife Service, personal communication). When wild brood are used, most agencies use catheters to remove eggs from females. The time until that female ovulates is then determined using techniques described below. Females that are greater than 15 hours from ovulation are released. Females that are projected to ovulate within 15 hours are transported to a hatchery and are stored in tanks until ovulation (Rees and Harrell 1990). An equal number of males of the opposite species are collected and are also kept in tanks in a hatchery. The brood fish are released or killed after spawning.

In order to induce spawning, female striped and white bass require injection with human chorionic gonadotropin (hCG; Rees and Harrell 1990). Injections are intra-muscular and are made in the region between the dorsal fin and lateral line. Female striped and white bass generally receive 300-330 IU hCG/kg (Rees and Harrell 1990; Suresh et al. 2000). Male white bass can be injected at 250 IU hCG/kg (Suresh et al. 2000). Male striped bass produce a large volume of sperm and typically do not receive an injection. After injection, the hatchery staff must wait 24-48 h for the females to ovulate. Egg color and internal structure can be used to gauge how far a female is from ovulation. Eggs can be removed for staging using a catheter. Several textbooks (e.g., Rees and Harrell 1990; Kerby 1993) present pictures of the egg development progression from hormone injection to ovulation. Fully ovulated striped bass eggs are transparent and the oil globule has completely coalesced. It also has a greenish tinge. The chorions are flexible and the eggs will be "hexagon" in shape when they compress against other eggs. Fully ovulated white bass eggs have similar properties as striped bass eggs, however, they typically have a slight yellow or gold tinge. It is important that the eggs are properly staged and are fertilized as soon as

they ovulate. If eggs are fertilized 30 min after they ovulate, an approximately 50% reduction in fertility occurs (Rees and Harrell 1990). That decrease in fertility is approximately 99% if fertilization is delayed by one hour (Rees and Harrell 1990). More often than not, eggs and sperm are removed by manual stripping. A "wet fertilization" method is preferred for hybrid striped bass. Typically, hatchery water or a 0.3% NaCl solution is used as a diluent. White bass are fractional spawners whereas striped bass spawn in a single bout. As a result, when the sunshine cross is produced, it is common for non-ovulated eggs to be mixed with ovulated eggs. This life-history facet should be accounted for when staging white bass eggs. The fertility of white bass eggs is typically ~40% lower than it is for striped bass eggs (Kerby 1993).

Striped and white bass eggs are notoriously sticky after fertilization. A number of methods have been developed for reducing egg adhesion. One method is to place the eggs in a 150 mg/L tannic acid solution for 10-12 min (Rottmann et al. 1988). When this method is used, the eggs are added to the tannic acid solution 1 min after fertilization. An airstone is used to keep the eggs suspended. Kerby and Harrell (1990) recommend a similar technique, however, they suggest a "pre-treatment" of 20 g NaCl, 15 g urea, and a small drop of antifoaming compound in 5 L of hatchery water. One or two minutes after fertilization, the eggs are added to the salt-urea solution and are vigorously aerated in that solution for 7-10 min. Then, the eggs are allowed to settle and water is decanted. Then, a 150 mg/L tannic acid solution is added and the eggs are aerated in that solution for 6-7 min. After tannic acid treatment, eggs are added to a hatching jar (~200 mL eggs/jar). No iodine disinfection is done with striped and white bass eggs. Flows in the jars are set so the eggs roll gently. The buoyancy of stiped and white bass eggs change during incubation. Frequently flow adjustments are required to maintain a gentle roll. The eggs generally hatch 45-55 h after fertilization. Eggs are typically incubated at a temperature of ~18°C. Striped and white bass eggs change color during incubation. Viable eggs often change to an opaque white color and should not be confused for dead eggs. Dead and fungused eggs should be siphoned from the jars during incubation.

After hatch, wiper can be kept in eyeing jars until swim-up (~4 d after hatch). Alternatively, they can be transferred to aquaria. During this post-hatch period, flows should be kept high enough that the fry are suspended. The jars or aquaria should be kept in a dark location. Many culturists prefer aquaria over eyeing jars (Rees and Harrell 1990). Generally, fry are added to aquaria at a density of 250-500/L. It is recommended that 4 d after hatch that wiper fry are stocked into ponds (Kerby 1993). Ponds should be filled shortly before the addition of fry and should be managed to maximize rotifer production. Fry are generally added at night at a rate of 225,000-550,000/ha. The fry can be maintained on a diet of rotifers and zooplankton until 50-75 mm TL (Rees and Harrell 1990). They can be stocked at this time. If larger fish are desired, culturists should train the fry to accept artificial feed. This is usually started 21-26 d post-hatch. The fry are fed a trout or salmon diet, 3 times a day, at a rate of 2-10 kg/ha/d. Feeding typically beings with a starter diet and the size of the feed increases as the fish grow. It is possible to rear fry in tanks. If tank rearing is performed, zooplankton will have to be provided until the fish reach 21-26 d post-hatch. Because of this limitation, most culturists who utilize tank culture start wiper fry in ponds and move them into tanks once they are trained to accept an artificial diet.

An alternative to the manual stripping of gametes is to allow the fish to spawn naturally in circular tanks. When this is done, one or two females and two to four males are added to a circular tank (1.2-2.4 m diameter, ~1.2 m deep; Kerby 1993). Both the male and female are injected with hCG. The brood are removed from the tank after spawning and the eggs are incubated and hatch in the tank (Smith and Whitehurst 1990). The advantage to this method is that the determination of the occurrence of ovulation is not necessary since the females will reproduce naturally when ovulation occurs (Smith and Whitehurst 1990). The primary disadvantage to this method is that it is less effective for the production of hybrid striped bass than it is for pure striped bass (Rees and Harrell 1990). Because tank spawning is not particularly effective for the production of wiper, it will not be discussed further.

Resources Required to Produce 100,000 Fish

Kerby (1993) states that typical hatch rates for wiper eggs are 25%. The same source also claims that survival from hatch to fingerling size is 10-30%. When the hatch and fry survival statistics are taken together, approximately 95% of taken eggs will die before the fish reaches 50 mm TL. Thus, for every 100,000 50 mm TL fingerling produced, approximately 2,000,000 eggs must be taken. The average female white bass produces 25,000 eggs (Kerby 1993) meaning that eggs must be obtained from 80 female brood annually. Since roughly 50% of females respond to hCG injection (Kerby 1993), 160 female brood should be collected to account for females that do not ovulate. Approximately 320 male striped bass should be collected to obtain a 2:1 sex ratio. With that said, striped bass produce a large volume of sperm and a single male striped bass could fertilize the eggs from several female white bass. Thus, the collection of as few as 20 males could be adequate. Typically, 100,000-150,000 eggs are placed into an eyeing jar. Therefore, 20 jars would be needed to incubate the eggs. Fry rearing densities range between 225,000-500,000/ha. A single hectare of pond area should be sufficient to rear 100,000 fry to 50 mm TL.

Warmwater Hatchery Design

The construction of a warmwater hatchery will be a major investment. It is important that the life-history and rearing strategies of the desired species are considered when designing a hatchery. Improper design can limit production. A good example of this exists at the Lee Kay Center. We are attempting to produce tiger muskellunge using a captive brood. Doing this has never been documented. Water temperatures at the Lee Kay Center are also warmer than ideal for tiger muskellunge culture. The limited success of the tiger muskellunge program can at least be partially attributed to these factors. Our hatchery crew has done an excellent job of producing fish with the resources in place at Lee Kay. If our tiger muskellunge program is more similar to what other states use, then, we would likely have greater success than what we currently have. Ultimately, our tiger muskellunge program may become highly successful, but, we are currently having to develop new strategies for the culture of the species. This development phase can be costly and means that it may take several years to develop a tiger muskellunge program that produces our desired number of fish. The Lee Kay Center can serve as a lesson for hatchery design. If we design a hatchery that is similar to what other agencies use, then we can rely on previously conducted research when developing rearing protocols. This will help a new hatchery reach its production goals faster and will ultimately save money and provide greater benefit to

anglers. If the design of a warmwater hatchery deviates too much from what other agencies use then it may require us to spend many years researching methods for the culture of the desired species.

Based on the surveyed literature, a warmwater hatchery that is capable of rearing a wide variety of species should provide precise temperature control in the range of 15-28°C (assuming that walleye and saugeye are not reared from a captive brood). A temperature range of 17-23°C may be adequate if walleye and channel catfish production is not desired. All of the warmwater species surveyed are most frequently reared in ponds. Thus, the incorporation of rearing ponds in the design of a warmwater hatchery would allow the Utah Division of Wildlife Resources to adopt rearing protocols that are similar to other agencies. With the exception of largemouth and smallmouth bass and crappie, all species have been reared in a recirculating facility. Recirculating facilities, however, are not the primary rearing facility for any warmwater species of interest in Utah. The use of recirculating facilities has been documented for the culture of all species except largemouth and smallmouth bass and crappie, but, the protocols for the production of warmwater fish in these facilities is poorly documented. Thus, more research may be required before a recirculating facility can be successfully used for warmwater fish culture in Utah. Regardless of the hatchery design used (pond or recirculating), any hatchery will require a building designated for the incubation of eggs and rearing of fry. Such a hatchery building should contain eyeing jars and numerous rearing troughs.

Tables 5 and 6 (below) summarize the rearing procedures for a number of warmwater species. These table should serve as a guide to the design of a warmwater facility. They contain information from the literature on the temperature requirements and rearing strategies for each species.

Table 5: Life-history information and previously utilized culture techniques for eight warmwater fish species that may be reared by the Utah Division of Wildlife Resources in the future.

Species	Egg Collection Method[a]	Eggs Incubated in Hatchery or Pond?[b]	Fry Rearing Location[c]	Brood Source[d]	Artificial Feed Acceptance[e]	Plankton Required for First Feeding?	Pond Culture Documented?	Tank Culture Documented?	Raceway Culture Documented?	Recycle System Culture Documented?	Recommended Dietary Protein Content (%)	Approximate Size 3 mo After Hatch (mm)
Bluegill	NP	P/H	P/T	W/C	R	Y	Y	Y	N	Y	35-36	50
C. Catfish	NP/CH	H	P/T	C	R	N	Y	Y	Y	Y	32	110
Crappie	NP	P	P	W	WT	Y	Y	N	N	N	40	75
LM Bass	NP	P	P	W/C	WT	Y	Y	N	N	N	40	100
Saugeye	WH/CH	H	P/T	W/C	WT	Y/N	Y	Y	N	Y	40	150
SM Bass	NP	P/H	P/T	W/C	WT	Y	Y	N	Y	N	40	100
Walleye	WH/CH	H	P/T	W/C	WT	Y/N	Y	Y	Y	Y	40	150
Wiper	WH/CH	H	P/T	W/C	WT	Y/N	Y	Y	Y	Y	38	150

[a] WH=Wild Handstripped Brood, CH= Captive Handstripped Brood, NP = Natural Pond Production

[b] H = In Hatching Jars, Trays, or Troughs, P = Cared for by Parents in Ponds

[c] T = Tanks or Troughs, P = Ponds

[d] W = Wild, C = Captive

[e] R = Readily, WT = With Training

Table 6: Optimal spawning, egg incubation, and growout temperature for a variety of warmwater fish species. Data was compiled from a number of sources.

Species	Spawning Temperature (°C)	Egg Incubation Temperature (°C)	Growout Temperature (°C)
Bluegill	19-23	19-23[a]	22-31
C. Catfish	21-29	21-29	22-32
Crappie	16-20	18-20	22-25
LM Bass	17-21	17-23[a]	20-30
Sauger	6-8	8-10	12-21
Saugeye	N/A	10-16	12-21
SM Bass	16-20	16-20[a]	20-30
Striped Bass	16-19	16-19	18-21
Walleye	6-11	10-15	10-20[b]
White Bass	16-18	16-18	25-30
Wiper	N/A	16-19	25-30

[a] Eggs normally incubated in-situ; optimal temperature assumed to be the same as spawning temperature

[b] 10-15°C initially then up to 20°C after feeding established

N/A indicates that data is not applicable because species does not naturally spawn

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